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Stand, Fuel, and Potential Fire Behavior Characteristics in an Irregular Southeastern Arizona Ponderosa Pine Stand

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Arizona's natural ponderosa pine stands are characterized by open, mature groups and adjacent closed, dense thickets. The open structure of the mature groups permits a warm, dry environment, resulting in very low fuel moisture during much of the fire season and creating high ignition and fire spread potentials in the abundant fuels. The large woody fuel component of the adjacent closed groups contributes to a high crown fire potential in the low, dense sapling crowns. These findings suggest a need for fuel management activities where values-at-risk are high.

Keywords: Fuel loadings, stand characteristics, fire behavior potential, *Pinus ponderosa* var. *arizonica*

Management Implications

A comprehensive study in a southern Arizona ponderosa pine (*Pinus ponderosa* var. *arizonica*) stand revealed differences in stand and fuel characteristics between open-structured, mature groups, and adjacent closed, dense groups. Widely spaced, old-growth pines characterized the open groups; dense, sapling thickets composed the closed groups. Total fuel loadings were nearly equal in the two groups, with the open groups having greater forest floor weights and the closed groups having more large woody fuels.

The openness of the old-growth groups allows a warm, dry microclimate, which is reflected in the dry fuel conditions. These conditions become extreme in the early summer months and cause a high ignition potential. Because fuels are plentiful and slopes are steep, there is a potential for high rates of fire spread and high fire intensities in these open groups. Woody fuel concentrations are a tremendous heat source; their presence in the adjacent closed groups—along with the low, interconnecting crowns—creates a hazardous crown fire potential.

The conditions described here create a high fire hazard situation. The information presented suggests a need for fuel management activities if a fire hazard reduction is sought, and it can assist in establishing priority areas for these activities. In addition, this improved understanding of fuel characteristics and potential behavior can be used to assure safer, more effective wildfire suppression action by concentrating efforts in open groups where crown fires are unlikely and large woody fuels are sparse.

Introduction

Southwestern ponderosa pine forests occur naturally as irregular, uneven-aged stands consisting of small, even-aged groups (Schubert 1974). Before settlement, wildfires burned in these forests at intervals of 5–12 years (Weaver 1951, Dieterich 1980), maintaining relatively low levels of fuel loading and thinning dense pine thickets (Biswell et al. 1973). Human activities, mainly fire suppression and livestock grazing, have permitted dense pine groups to remain unchanged for decades (Weaver 1951, Cooper 1960). Considerable fuel has ac-

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cumulated (Sackett 1979, 1980) over fire-free periods of up to 100 years (Dieterich 1980).

The combination of heavy fuel accumulations and dense sapling groups creates a severe fire hazard, especially during the extended period of critical fire weather experienced in the Southwest (Schroeder et al. 1964). The objectives of this study were to (1) analyze and compare stand and fuel characteristics of open, old-growth forest groups and adjacent closed, overstocked groups in a southeastern Arizona ponderosa pine stand, and (2) use these characteristics with weather and historic fire data to interpret the potential fire behavior and evaluate the fire hazard.

Study Site

The study area is in the Santa Catalina Mountains of the Coronado National Forest where there is a very high incidence of lightning and human-caused fires (Harrington 1981). The study was conducted on a southwest aspect with slopes ranging from 30% to 50%; elevation is 8000 feet. The forest is composed of many uneven-aged stands with even-aged groups. The stand under study is composed predominantly of a 5-needled, southwestern variety of ponderosa pine with a mixture of southwestern white pine (*Pinus strobiformis*), Douglas-fir (*Pseudotsuga menziesii*), and silver leaf oak (*Quercus hypoleucoides*). This site has had no cutting treatments and has remained unburned for about 70 years.[2]

Methods

Stand and fuel sampling methods follow those in Harrington (1981), and are also detailed here. Eighteen plots were established for stand and fuel sampling on a 9-acre unit. Nine plots were in open groups dominated by large old-growth pines, and nine were in closed groups consisting of overstocked clumps of ponderosa saplings, commonly called doghair thickets (fig. 1). Each plot consisted of a nonrandom, 3-by-3 grid, with the nine sample points spaced 20- to 25-feet apart, depending on group sizes. To estimate loadings of the forest floor needle and woody fuels smaller than 1 inch in diameter, a 1-square-foot sample from each of the nine sample points was cut to mineral soil, bagged, and returned to the laboratory for oven-dry weighing. Total forest floor weight was determined for five of the nine collections. The other four collections were separated into three distinct stages of forest floor decomposition: L (litter), F (fermentation), and H (humus), as described in Harrington (1981). The weights of specific components of each layer (needles, 0- to 0.25-inch twigs, 0.25- to 1-inch twigs, oak leaves, bark, and cone parts) were determined. Four forest floor depth measurements were taken for each square foot of material removed. The weights and depths for these nine sample point were averaged to yield one observation per plot.

Downed, woody fuel with diameters between 1 and 3 inches was sampled along three transects running across the plot between the sample points. Intercepts of fuels in this size class were counted, and a weight per area was determined using Brown's (1974) method.

The length and mid-diameters of all downed, woody fuel pieces greater than 3 inches in diameter were measured within a 0.05-acre circular sample. Only that portion of fuel pieces which fell within the 0.05 acre was measured. Fuel volumes were computed from the length and diameter measurements, and weights were determined using standard densities of either sound or rotten woody material sampled (Brown 1974).

To estimate stand characteristics in each plot, the diameter at breast height and species of each tree occurring within a 0.067-acre circular sample were recorded.

[2]*Data on file, Fuel Management Research Project, Forestry Sciences Laboratory, Tempe, Ariz.*

Figure 1.—Ponderosa pine stand with closed group on the left and open group on the right.

Fuel moisture determinations were made during the summer of 1979. Details of that study are published elsewhere (Harrington 1982).

Statistical comparisons of fuel and stand characteristics between the open and closed groups were made using *t*-tests. Levels of significance (*P*) are stated.

Results and Discussion

Stand Characteristics

Stand differences between the open and closed groups were visually obvious (fig. 1). Average values of overstory characteristics for the nine plots in each group, reported in Harrington (1981), are resummarized with standard deviations:

	Open groups	Closed groups
D.b.h. (inches)	5.2 ± 2.6	2.5 ± 0.5
Trees per acre	603 ± 343	3,512 ± 887
Basal area (square feet per acre)	206 ± 64	186 ± 31

The open groups had significantly fewer trees than the closed groups but the trees were significantly larger ($P < 1\%$). Basal areas were not significantly different ($P > 5\%$).

Figure 2 shows trees per acre for each group by d.b.h. size class. The closed groups had greater tree densities ($P < 1\%$) in all except the largest size class, where the open groups were significantly more dense ($P < 1\%$). The large number of trees in the smallest size classes in both groups is probably the result of fire exclusion. This response was more pronounced in the closed groups.

Even though total group basal areas were similar, basal area by d.b.h. size class differed greatly between groups (fig. 2). Large, mature pines dominated the open groups. These trees determine this group's fuel characteristics to a great extent. The four largest size classes in the closed groups had a more even distribution of basal area, ranging from 12% to 36% of the total. No size class completely dominated, as in the open group.

The sapling class of the closed groups was between 60 and 70 years of age, which roughly coincided with the approximate time since the area last burned 65 to

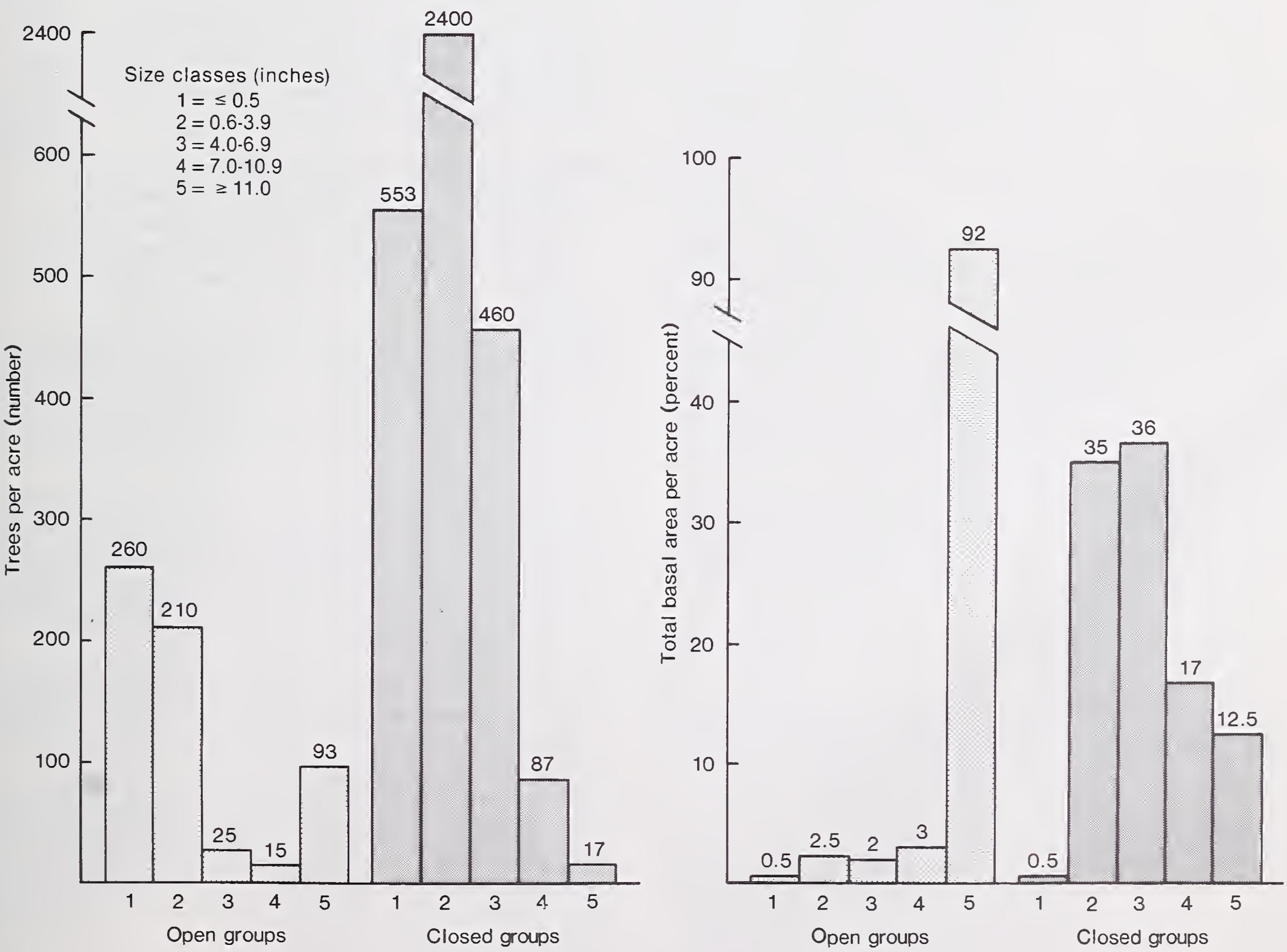

Figure 2.—Number of trees per acre and percent total basal area per acre by tree size class within groups.

75 years ago.[2] That last fire likely created the seedbed for establishment of the overstocked thickets seen today.

Fuel Characteristics

Table 1 (Harrington 1981) shows a comparison of adjacent open and closed group fuel loadings. Forest floor and total fuel weights at this site were much greater than those of other Arizona ponderosa pine stands (Gaines et al. 1958; Ffolliott et al. 1968, 1976; Sackett 1980). Sackett's (1980) study was the only one reporting information from undisturbed stands. In a comprehensive study of southwestern ponderosa pine fuel loadings (Sackett 1979), needle and forest floor weights averaged about 50% less than those shown in table 1. Amounts of woody fuels less than 3 inches in diameter were sparse, but about equal in both studies. Loadings of sound and rotten woody fuels greater than 3 inches in diameter were extremely variable but similar in both studies when open and closed group loadings in this study were combined to get a stand average.

Table 1 reveals some differences in fuel weights between groups. The large number of small trees in the closed groups probably produced the slightly greater amounts of ≤0.25-inch twigs. The majority of the miscellaneous weight was bark and cones, which were found in greater quantities near the thick-barked, cone-producing mature pines in the open areas. Even though the miscellaneous and ≤3-inch woody fuel loadings were statistically different between groups at a moderate level of significance, these differences, along with those of the ≤0.25-inch twig loadings, were so small that they would most likely produce little real differences in fire behavior or effects. The dissimilarity of needle and forest floor loadings between groups was probably the result of the older groups of trees depositing litter for a longer period of time (over 100 years, based on group age differences).

The fuels that burn in the passing fire front and, therefore, those that determine fireline intensity, are generally the ≤1-inch fuels in the entire L layer and a portion of the F layer. The amounts available for combustion are determined largely by fuel moisture and ambient weather conditions. Expressing loadings of ≤1-inch fuel by forest floor layer reveals where real differences occurred and how they might be important.

Forest floor layer	Open groups	Closed groups
	tons per acre	
L (litter)	2.0	2.2
F (fermentation)	10.9	9.2
H (humus)	15.8	12.0

Fuel loading differences between groups for the upper two layers were slight. Therefore, a comparable and substantial amount of fuel would be available for burning in the fire front in the L layer and upper portion of the F layer in both groups under similar weather and fuel moisture conditions.

However, microclimate and fuel moisture conditions are rarely similar in the two groups. Sparse canopy coverage in the openings allows more direct sun on the fuels, causing warmer fuel temperatures which combine with low humidities to produce very dry fuels, as Jemison (1934), Simard (1968), and Countryman (1977) reported. These hazardous conditions are common in the early summer in southeastern Arizona. Table 2 illustrates these differences using fuel moisture data collected from the study site in 1979.

With fine fuel moisture between 5% and 10%, risk of ignition is high, combustion is rapid, and occasional-to-frequent crowning may be expected. With fine fuel

Table 1.—A comparison of adjacent open and closed group fuel loadings

Fuel components	Fuel loadings: Open groups	Fuel loadings: Closed groups	Significance level
	tons per acre		*percent*
Needles/humus	24.2 ± [1]4.5	19.9 ± 3.7	5
0- to 0.25-inch twigs	0.3 ± 0.1	0.4 ± 0.2	10
0.25- to 1-inch twigs	1.0 ± 0.4	1.0 ± 0.4	>50
Miscellaneous	3.2 ± 1.4	2.1 ± 0.9	10
Total ≤1-inch material (forest floor)	28.7 ± 4.4	23.4 ± 3.5	2
Total 1- to 3-inch woody material	0.7 ± 0.3	0.9 ± 0.2	10
>3-inch sound material	1.0 ± 0.5	4.0 ± 1.9	10
>3-inch rotten material	3.1 ± 2.1	6.0 ± 1.0	10
Total >3-inch woody material	4.1 ± 2.0	10.0 ± 2.0	5
Total fuel loading	33.5 ± 5.3	34.3 ± 8.5	>50

[1]*Standard deviation*

Table 2.—Number of days when L-layer needle moisture was below 5% and 5-10% in June and July 1979

Month	Groups	Fuel moisture	
		5-10%	< 5%
June	Open	26	17
	Closed	23	10
July	Open	22	12
	Closed	19	5

moisture less than 5%, ignition occurs very easily, burning conditions are critical, and spot fires are common.[3] Even though the area received more than twice its average rainfall in June 1979, the fuel moisture in both groups was very low (5–10%) on 75% of the days and critical (< 5%) more than 30% of the days, with the open group having 7 more days of critically low fuel moisture (table 2). July had fewer, but still a large number of days with low fuel moisture, more than one-half of which were critically low in the open group. In 7 of 16 years, weather records collected near this study site show May and June rainfall amounts have been less than 0.25-inch. To further illustrate these critical burning conditions, there were only 2 days in June 1980 with measurable rainfall, permitting the 1-hour timelag fuel moisture, which is a good representative of fine fuel moisture (Harrington 1982), to reach 5% or less on 28 of 30 days.

The tabulation above shows that the open groups had approximately 24% more humus than the closed groups. While this type of fuel has little influence on maximum fireline intensity, when dry enough for combustion, the heavier H layer loadings invariably lead to extended burning time, greater total energy release, more severe fire effects, and more suppression difficulties (Brown and Davis 1973).

The average depths of the forest floor material were statistically equal, with values of 2.9 inches and 2.7 inches for the open and closed groups, respectively. Therefore, the same fuel that had significantly greater weights in the open groups (table 1) had similar depths in both groups, indicating a difference in bulk density. The average open group bulk density was 5.7 pounds per cubic foot, which was greater ($P < 1\%$) than the 4.8 pounds per cubic foot in the closed groups. This difference was likely due to dissimilar amounts of H layer fuel, which is known to have the greatest density of the three forest floor layers (Brown 1966, Ffolliott et al. 1968). Although the bulk densities of the individual layers were not measured, insignificant density differences between groups were assumed in the upper layers because of nearly equal total loadings and similar amounts of specific fuel components. The effects of slight differences in bulk density on rates of fuel drying and combustion would certainly be overshadowed by contrasting weather and fuel moisture conditions between groups.

[3]*Information compiled by Hal E. Anderson, USDA Forest Service, Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, for Fire Behavior Officer Training (National Interagency Training Center, Marana Air Park, Arizona).*

The greatest total energy release, greatest crowning potential, and most severe fire effects probably occur as heavy fuels (> 3-inch woody fuels) burn. The closed groups had high concentrations of large woody fuels, with individual plot loadings ranging from 0.2 to 23.2 tons per acre and averaging 10 tons per acre. The presence of these large fuels contribute to crowning and increase spotting potential because of the low, interconnecting sapoling crowns, a condition similar to that described by Kilgore and Sando (1975). Fahnestock (1968) and Hirsch et al. (1979) indicated that large fires very often result from torching or crowning of "doghair" groups similar to those described here. The heavy fuel loading in the open groups was less than one-half (4.1 tons per acre) of that in the closed groups. These light loadings and sparse stand structures would prohibit crowning in other than small seedling patches.

Conclusions

For much of the long fire season in the Santa Catalina Mountains, ignition potential, especially in the open timber groups, is quite high. Warm, dry weather and dry fuels combine with a high risk of lightning and human-caused fires to create this situation. These conditions also result in high fire intensity and high spread potential because of the heavy fuel floadings and steep slopes.

Because the open and closed groups are contiguous, a fire starting in an open group can move quickly into one or more closed groups. Depending on weather and fuel conditions, the fire would move through the closed group with varying intensities, or be extinguished. The latter situation would occur when surface fuels of the closed groups are at or above the moisture of extinction even though fuels outside this group are dry enough to carry a fire. Under extreme fire weather and fuel moisture conditions, a fire in a closed group would spread rapidly in the pine needle fuels. It could ignite the low seedling and sapling crowns from the burning of the forest floor alone, and would inevitably cause individual torching or group crowning and possible spotting with the combustion of the plentiful, larger woody fuels. Under windy conditions, running crown fires could be expected in the dense sapling stands on these steep slopes. Spotting potential would be high. When a crown fire reached an open group, it would likely drop to the ground because of sparse aerial fuels, but would continue its spread. This wildfire situation can commonly occur, especially under conditions of heavy fuel loadings, dense sapling stands, steep slopes, and extended dry weather, all of which are common in the Santa Catalina Mountains and probably elsewhere in Arizona.

These factors, coupled with high fire frequency, presence of numerous forest homes, recreation areas, and electronic and other scientific installations, strongly suggest the need for continuous, effective fuel management activities if a reduction in the probability of a major disastrous fire is desired.

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